Micromesh “Spider-web” Bolometers for Astrophysics

We are developing high sensitivity arrays of bolometric detectors for far-infrared to millimeter-wave astrophysics. Micromesh “spider-web” bolometers operating from 0.1 - 0.3 K offer sensitivity limited by photon noise from the astrophysical sky brightness. The micromesh architecture allows for minimal heat capacity, suspended mass, and cosmic-ray cross-section from the infrared absorber. The thermal isolation of the silicon nitride support legs offers the possibility of low thermal conductivity and correspondingly high sensitivity (NEP ~ 10^{-19} W/$\sqrt{\mathrm{Hz}}$ at 0.1 K). The detector architecture may be coupled to transition-edge-superconducting (TES) or semiconducting (NTD Ge) thermistor technologies. Devices with NTD Ge thermistors achieve high 1/f noise stability, to frequencies ν < 30 mHz. The ESA/NASA Planck and FIRST satellites have selected arrays of micromesh bolometers to measure the anisotropy and polarization of the cosmic microwave background, to catalog the Sunyaev-Zel'dovich effect in clusters of galaxies, and survey far-infared luminous galaxies at cosmological distances.

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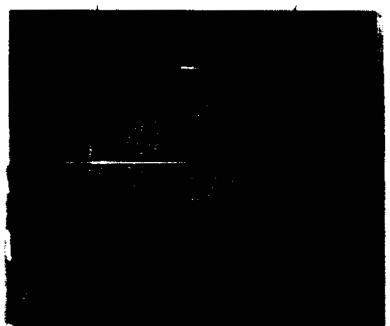
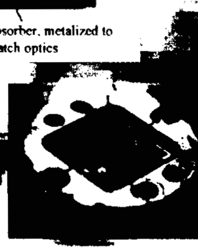
Micromesh Bolometers

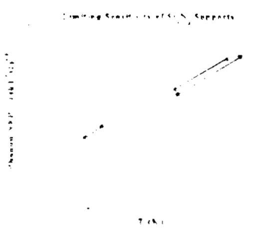


Micromesh architecture offers several advantages:

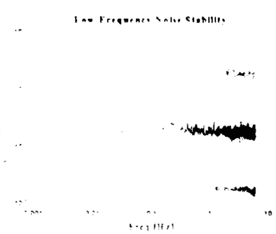
- minimal absorber heat capacity
- fast internal time constants (< 1 ms)
- minimal suspended mass
- low cosmic ray cross-section
- low thermal conductivity = high sensitivity
- low 1/f noise (<30mHz) with NTD Ge
- ease of fabrication



Single-element micromesh bolometer

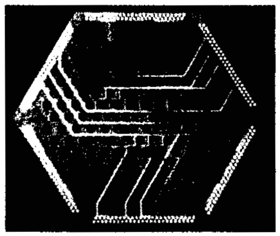


Limiting phonon sensitivity of silicon nitride supports measured is ~10 W/√Hz at 0.1 K, extrapolated from 0.3 K data (green points). Black data show achieved bolometer NEPs

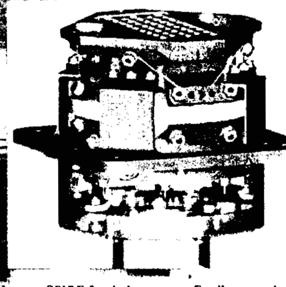


Achieved 1/f stability under optical load for three detectors in bolometer arrays (plots are each scaled by a factor of 10).

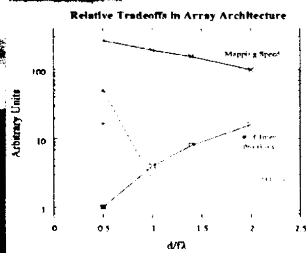
Feedhorn-Coupled Bolometer Arrays



163-element array for SPIRE at λ = 350 mm



SPIRE focal plane array. Feedhorns and bolometers are thermally isolated from 2 K by a kevlar mechanical structure.



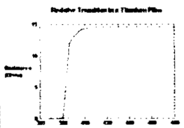
The relative tradeoffs between 2fλ, 1.4fλ and 1fλ feedhorns and a Nyquist-sampled 0.5fλ bare array assuming background-limited sensitivity. Feedhorns have better coupling to point sources, but require dithering to make a map.

The bolometer arrays for FIRST will be feedhorn-coupled. A monolithic array of bolometers placed behind a closely-packed array of concentrating scalar feedhorns realizes maximum sensitivity per detector, with space between each detector for planar readouts. Feedhorns control the field of view of the array, achieve high optical efficiency (> 85 %), and require 16 times fewer detectors than a Nyquist-sampled bare array.

Transition-Edge Superconducting Bolometers

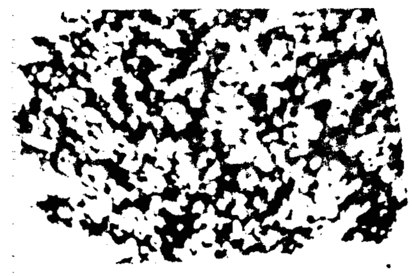
TES sensor on micromesh absorber

Voltage-biased transition edge superconducting (TES) bolometers offer advantages over semiconducting thermistors. TES bolometers are dominated by electro-thermal feedback (ETF) due to the steepness of the superconducting transition. ETF acts to compensate electrical power for changes in the optical loading, maintaining the film at its transition temperature, with ~100 times faster speed of response than $\tau = C/G$. TES bolometers are readout with a SQUID current amplifier. The low noise (~pA/$\sqrt{\mathrm{Hz}}$) and power dissipation (~nW) of SQUIDs enables multiplexing at the sub-K stage.

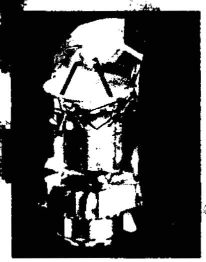


TransitionTemperature of Titanium film $\alpha = \delta \ln R / \delta \ln T \sim 275$

Cosmology



First resolved map of CMB Anisotropy obtained with micromesh bolometers on the BOOMERANG Antarctic balloon flight. The minute temperature fluctuations in this map trace the interaction of photons and matter when the universe was just 300,000 years old. The characteristic structures serve as a thumbprint telling us the geometry of the universe, and the relative abundance of all forms of matter and energy density.



The ESA/NASA Planck and FIRST missions will use arrays of micromesh bolometers to study the CMB and the formation of galaxies in the early universe. Planck will map 30,000 times more sky than BOOMERANG with better sensitivity and frequency coverage.

Micromesh bolometers are incorporated into numerous pioneering balloon-borne and ground-based experiments, such as BOOMERANG (left) and BOLOCAM on the Caltech Submillimeter Observatory (right).